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Diffusion in the Vicinity of Standard-Design Nuclear Power Plants-I. Wind-Tunnel Evaluation of Diffusive Characteristics of a Simulated Suburban Neutral Atmospheric Boundary Layer

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16. ABSTRACT

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DIFFUSION IN THE VICINITY OF STANDARD-DESIGN NUCLEAR POWER PLANTS—I

WIND-TUNNEL EVALUATION OF DIFFUSIVE CHARACTERISTICS OF A SIMULATED SUBURBAN NEUTRAL ATMOSPHERIC BOUNDARY LAYER

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Abstract—A large meteorological wind tunnel was used to simulate a suburban atmospheric boundary layer. The model-prototype scale was 1:300 and the roughness length was approximately 1.0 m full scale. The model boundary layer simulated full scale dispersion from ground-level and elevated release points over surfaces of comparable roughness length. This information should prove useful in a variety of transport and diffusion studies over short to moderate downwind distances. It will be used in Part II as the baseline data set with which to compare diffusion downwind of standard-design nuclear power plants.

INTRODUCTION

THE DETERMINATION of diffusion parameters for the calculation of radioactive or conventional pollutant concentrations in the atmosphere is a critical step in an assessment of environmental impact. Plume spreading caused by turbulence occurs as the plume travels downwind. The rate of dilution in the plume can vary drastically depending on many factors, e.g. wind speed, wind direction, stability, release height, surface roughness, and building and topographical effects. Determining appropriate diffusion parameters is essential if the atmospheric situation under investigation is to be accurately described.

The present investigation was aimed toward developing a diffusion parameter data set and comparing this data set with the most commonly used atmospheric parameters and recent field data. The investigation developed dispersion parameters for a simulated suburban atmospheric flow using fluid modeling techniques. Parameters were experimentally determined for isolated stack releases at various stack heights. Thus, the dispersion of a plume released from an isolated stack immersed in a neutrally stable suburban atmospheric boundary layer was simulated.

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This information should prove useful in a variety of transport and diffusion studies over short to moderate downwind distances. These dispersion parameters will be used as the baseline data set with which to compare diffusion downwind of standard-design nuclear power plants, to be presented in Part II.

EXPERIMENTAL EQUIPMENT AND PROCEDURES

The meteorological wind tunnel

The study was undertaken in the EPA Meteorological Wind Tunnel (MWT). It is an ultra-low speed, open-return wind tunnel with a test section 2.1 m high, 3.7 m wide and 18.3 m long. Air entering the tunnel passes through a honeycomb, a series of four screens, and a 2.8:1 contraction prior to entering the test section. After the test section, the air flows through an acoustic silencer, a rectangular to round transition section, the fan, a diffuser, and another acoustic silencer before being exhausted back into the room. The ceiling height of the test section can be adjusted to compensate for blockage effects of a model and/or to obtain a zero-pressure gradient within the test section. An instrument carriage can position a probe anywhere within a $17 \times 3 \times 1.5$ m volume with accuracy of 1 mm. Laboratory data are sampled, processed, and stored by a Digital Equipment Corporation PDP 11/40 minicomputer. Real-time capabilities and disk or magnetic tape storage provide instant feedback on data being taken as well as easy access for later analysis. A detailed description of the wind tunnel and instrumentation are given by Snyder (Sn79).

Design of the experiment

An important objective was to simulate, in the wind tunnel, a suburban atmospheric boundary layer. The term suburban is used to indicate an intermediate surface roughness as opposed to the residential or outlying part of a city or town. A suburban boundary layer flow is intermediate between those over rural and urban terrain, i.e. arable, forested, or outlying parts of cities or towns. In conjunction, experimentally determined diffusion coefficients for this boundary layer were compared with the atmospheric values of Turner (Tu70), Vogt (Vo77), and McElroy (Mc69), which are frequently applied.

An isolated stack release was used to determine the dispersion parameters. The study focused on near-field effluent concentrations in the range to approx. 3 km downwind of the stack. A model-to-prototype scale ratio of 1:300 was followed. The stack was a 0.56 cm I.D. brass tube with a 90° bend near the exit to avoid any cross-stream momentum in the effluent. The effluent flow rate was adjusted to maintain an isokinetic release based on the inside diameter of the stack. Release heights of 15 mm (just above the roughness elements on the floor of the wind tunnel), 166 mm, and 333 mm corresponded to full-scale releases of ground-level, 50 and 100 m, respectively.

The simulation of a horizontally homogeneous suburban atmospheric boundary layer was necessary in order to make later determinations of building wake effects. Accurate measurements of the flow and dispersion associated with this undisturbed boundary layer were required. Considerable effort was expended developing the boundary layer. Several wind tunnel arrangements were used and analyzed before an appropriate boundary layer was achieved. Different wind tunnel arrangements were produced by utilizing different combinations of roughness elements, barrier heights, barrier shapes, and vortex generators. Criteria used in selecting the proper wind tunnel arrangement were (1) an adequate fit to the power-law and log-law equations that were used to describe the boundary layer, (2) an adequate boundary layer depth, (3) a large enough roughness length z_0 and (4) laterally homogeneous velocity profiles.

Similarity criteria

In order for the behavior of the flow in the MWT to simulate that in the atmosphere, it was necessary to match certain nondimensional parameters (Sn72, 81). For the present study, the parameters of significance were h_s/δ, W/U and WD/ν. The stack height to boundary layer thickness ratio, h_s/δ, satisfied

the similarity criteria because the isolated stack was appropriately scaled. The effluent exit speed to wind speed ratio, W/U, was not matched because the intention was to simulate a point source. Instead, as mentioned earlier, the stack was bent-over and W/U was adjusted to maintain an isokinetic flow. The effluent Reynolds numbers ranged from 1250 to 2050, somewhat below the minimum value of 2300 recommended by Snyder (Sn81). However, since the stack contained a sharp bend within 10 diameters of the exit, the effluent flow was fully turbulent upon release (Li76). This technique enabled the plume behavior to be independent of effluent Reynolds number (Sn76).

Wind tunnel arrangement

The simulated flow should possess properties characteristic of the appropriate atmospheric flow. In the wind tunnel, to observe plume dispersion or building wake effects in a boundary layer, the undisturbed flow must be essentially two-dimensional and changing very little in the streamwise direction. Subsequent to the initial development, the simulated flow becomes a typical boundary layer flow and it is appropriate to compare the properties of the developed flow with those of naturally grown boundary layer flows. In the present study, a simulated neutrally stable "suburban" flow was compared to its full-scale counterpart.

Careful consideration was given to the boundary layer generation scheme because a specific boundary layer was desired, i.e. suburban. The parameters of primary concern were the roughness length z_0, the power-law index p, and the boundary layer depth δ. Suggested values for full-scale suburban boundary layers (Wi78, Ka77, Ca75 and Co75) are:

$$1.0 \le z_0 \le 1.5 \text{ m}$$
$$1/6 \le p \le 1/4$$
$$150 \le \delta \le 600 \text{ m}.$$

The experimental technique used to simulate this boundary layer consisted of a straight barrier 235 mm in height placed at the entrance to the test section. The floor of the test section was covered with three-dimensional roughness elements measuring 14 × 14 × 150 mm on 150 mm centers (Fig. 1). This boundary layer development scheme evolved from that described by Counihan (Co69).

Positions in the wind tunnel are represented by a rectangular Cartesian coordinate system where x, y and z are defined as the longitudinal, lateral and vertical directions,

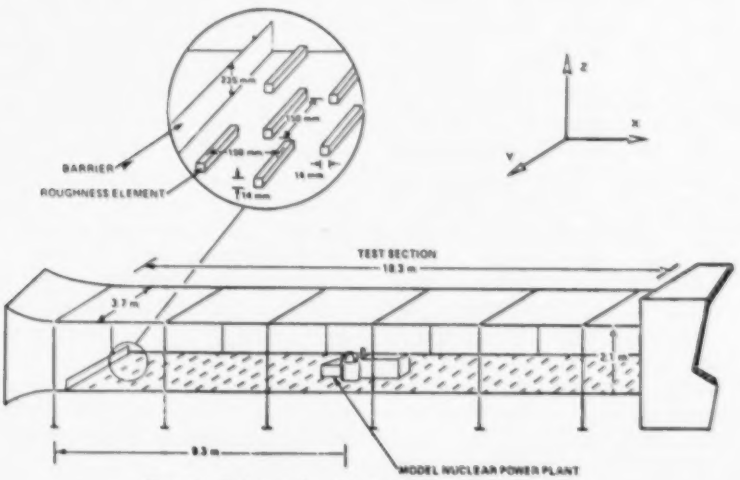

FIG. 1. Schematic of wind tunnel test section.

respectively, and U, V and W are the velocities in the x, y and z directions, respectively. The origin for all undisturbed flow measurements, i.e. without the stack was located at the beginning of the roughness elements, immediately behind the barrier ($x = 0$), at the centerline of the tunnel ($y = 0$), and on the floor ($z = 0$). With the stack in position, $x = 0$ was at the point of release from the stack, 9.3 m downwind of the barrier. Figure 1 shows the wind tunnel arrangement, where the isolated stack was positioned at the model location.

Velocity measurements

Velocity and turbulence measurements were made with Thermo-Systems, Inc. (TSI) constant temperature anemometers. Two types of anemometer probes were used. Most measurements were taken with a TSI model 1210–20 hot-film probe, which provided information on streamwise velocities and turbulence intensities. Corroborative measurements were made with a TSI model 1241–20 cross, hot-film end-flow probe. The cross-film probe provided the capability of two-dimensional velocity and turbulence intensity measurements. The anemometer output signals were digitized at a rate of 250 samples/s, linearized, and processed on the PDP-11/40 minicomputer. A freestream wind speed of 6 m/s was used for all quantitative measurements. Repeatable results (approx. ± 1% mean velocity) were acquired using the sampling time of 60 s.

Anemometer calibration curves were determined in the freestream flow. The hot-film probes were calibrated by placing them adjacent to a pitot tube for comparison. Six to eight calibration points were established over the velocity range 1.5–8.5 m/s. The best fit to King's form, $E^2 = A + BU^\alpha$, was determined, where E is the output voltage of the anemometer, U is the mean velocity, and A, B and α are constants determined during calibration. The best fit was associated with the α that minimized the sum of the squared errors, determined through an iterative procedure on the minicomputer. The mean velocity was independently monitored during the measurement period using a pitot tube and micromanometer.

Velocity profiles were acquired by the computer sampling the anemometer output. A reference table of digitized voltage vs velocity was generated according to the best-fit values of A, B and α acquired from the calibration. During the sampling period, mean velocities, root-mean-square (rms) velocities and turbulence intensities were computed. Due to the sensitivity of the hot-film probes to ambient temperature, the room temperature was monitored continuously. If a temperature change in excess of 0.5°C was observed, corrections to the hot-film response were made according to the method of Bruun (Br75).

Concentration measurements

Ethylene gas was used as a tracer. Concentration profiles were obtained using a Beckman model 400 Hydrocarbon Analyzer (flame ionization detector, FID) in the continuous operating mode. Samples were collected through 1.6 mm teflon tubing with a short brass tube inserted in the end as a sampling probe. The brass tube was mounted on the instrument carriage and stepped through the hydrocarbon plume such that the intake gas was analyzed by the FID for its hydrocarbon content at each location.

The FID was calibrated each day prior to use. Zero air, with less than 1 ppm total hydrocarbon, was used to set the "zero" or minimum detection level of the FID. A 1% methane (CH_4) gas was used to set the "span" or maximum level of detection. Ethylene (C_2H_4–99% pure) was chosen as the tracer gas due to its neutral buoyancy in air. (Ethylene and air have molecular weights of approximately the same value, 28.0 and 28.9, respectively.) Because the number of carbon atoms of the tracer gas differed from that of the calibration gas, it was necessary to determine appropriate "response factors" for each gas. Calibration curves for the two gases are shown in Fig. 2. Response factors were determined to be 1.0 and 1.6 for methane and ethylene, respectively. These response factors were used to normalize the data relative to the calibration standards (methane). The response of the FID was linear for both gases in the measurement region (Fig. 2). The "zero" and "span" were checked after the

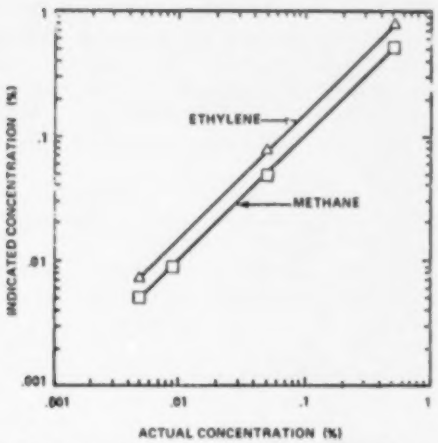

FIG. 2. Flame ionization detector calibration curves for methane and ethylene.

measurement of each profile to ensure that the electronics had not drifted.

The output of the FID was processed by the PDP-11/40 minicomputer. The background level of hydrocarbons in the room air slowly increased during the sequence of concentration measurements because the tunnel air recirculated through the room. To correct for this increase, background concentration measurements were taken periodically during the experiment, at least at the beginning and end of each profile, and occasionally more frequently. A computer program would bracket data between adjacent background measurements, subtracting the background hydrocarbon concentration from the sample concentration by assuming a linear change in background with time between sequential measurements. The response time of the FID was approx. 0.5 s, too large to obtain useful statistics on concentration fluctuations.

RESULTS AND DISCUSSION

Velocity measurements

To examine the development of the boundary layer, vertical profiles were measured at various longitudinal positions on the centerline of the tunnel. Mean velocity profiles acquired at 4.0, 8.0, 11.5 and 15.0 m downwind of the barrier are displayed in Fig. 3. The boundary layer was not completely developed at $x_m = 4.0$ m as shown by the flatness of the profile at heights between 150 and 400 mm. This abnormality is barely discernible at 8 m and is absent farther downstream. For practical purposes, it may be concluded that the boundary layer was fully developed beyond $x_m = 9.0$ m.

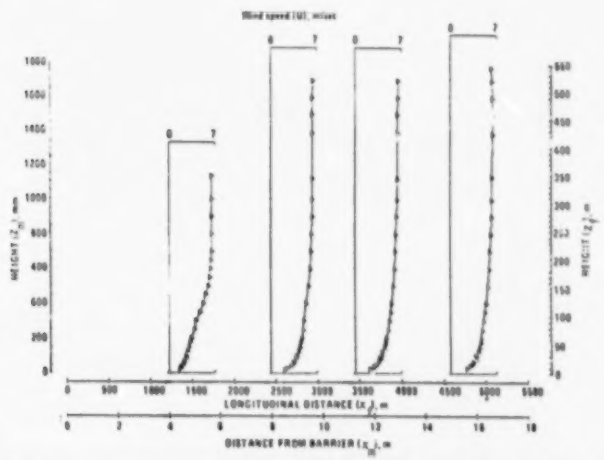

FIG. 3. Development of mean velocity profile along centerline of wind tunnel.

Lateral profiles were taken at several downwind distances to examine horizontal homogeneity. In all cases where the vortex generators were used adjacent to the barrier, there were nonuniformities. Figure 4 shows examples of lateral velocity profiles with and without the vortex generators. The final wind tunnel arrangement did not use vortex generators.

Figure 5 shows the development of the turbulence intensity profile as a function of downstream distance. The turbulence intensity decreases at the top of the fully developed boundary layer to approx. 10% of that near the surface. These profiles also indicate fully developed flow beyond $x_m = 9$ m.

A sequence of semi-log plots of wind speed vs height is presented in Fig. 6. The straight line requirement of a fully developed flow is emphasized dramatically in the figure. Obviously the flow had not fully developed by $x_m = 4.0$ m, but had adequately developed by 8.0 m. The boundary layer depth δ was approximately 1250 mm. Extrapolation of these curves to zero wind speed indicates values of 3.0–3.3 mm for the roughness length z_0 in the fully developed flow. A least-squares fit to the lower 20% of the data at $x_m = 11.5$ m showed z_0 to be 3.1 mm or approx. 1.0 m at full scale.

These experiments led to positioning the isolated stack at the upwind edge of the "fully developed" boundary layer. The boundary layer was obviously developing throughout the length of the test section. However, it could be considered fully developed at approx. $x_m = 9.0$ m, since development thereafter was minimal (Figs. 3, 5 and 6). The stack was placed 9.3 m from the barrier, allowing 9.0 m of test section available for downstream measurements (2.7 km full scale).

A comparison of the parameters determined in the present study with those of simulated and atmospheric flows obtained by other investigators is shown in Table 1. Agreement is

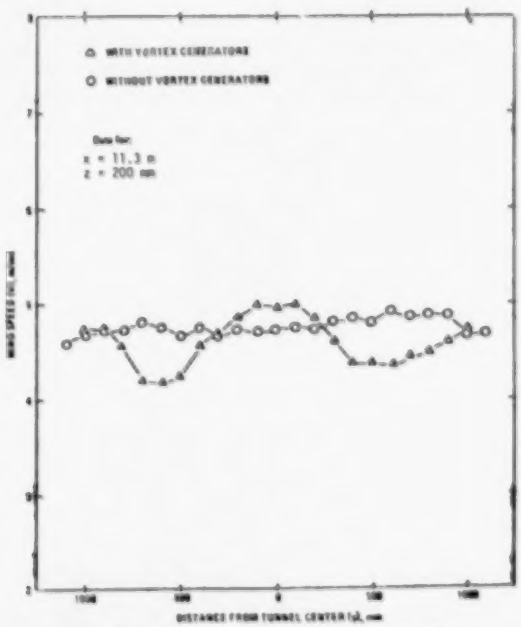

FIG. 4. Lateral profiles of mean velocity.

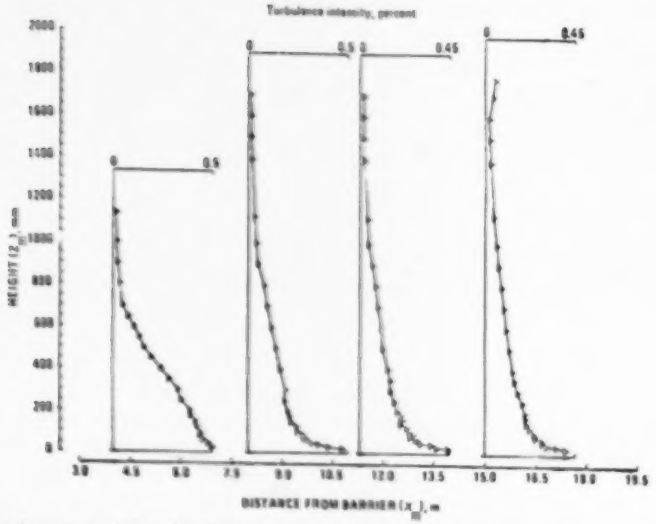

FIG. 5. Development of longitudinal turbulence intensity along centerline of wind tunnel.

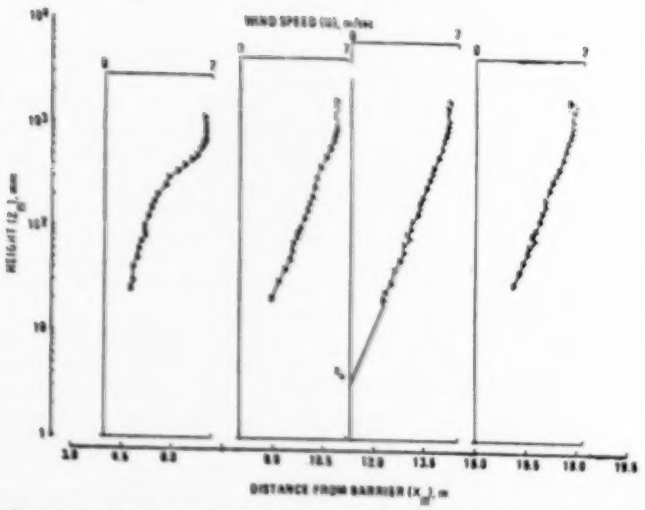

FIG. 6. Development of mean velocity profile in log–law form along centerline of wind tunnel.

Table 1. Parameter comparisons of simulated and full-scale atmospheric flows

REFERENCE	FLOW TYPE	SCALE	BOUNDARY LAYER DEPTH, δ (m)	ROUGHNESS LENGTH z_o (m)	POWER-LAW INDEX p	FRICTION VELOCITY u_*/U_∞
Present Study	Simulated Suburban	1:300	375	1.0	0.17	0.07
Ro 78	Simulated Urban	1:300	600	1.3	0.22	0.063
Ca 75	Simulated Urban	1:300	600	1.3	0.20	0.065
Co 75	Full-Scale Suburban	1:1	600	1.0-1.5	0.20	0.045-0.055

good. The friction velocity u_*/U_∞ is slightly higher than obtained by other investigators. It was determined from the slope of the semi-log plot of the mean velocity profile (Fig. 6); direct measurements with cross-film anemometry tend to be lower (Ca80).

Figure 7 shows a vertical profile of mean velocity at $x_m = 11.5$ m. The data fit well to a 1/6 power law.

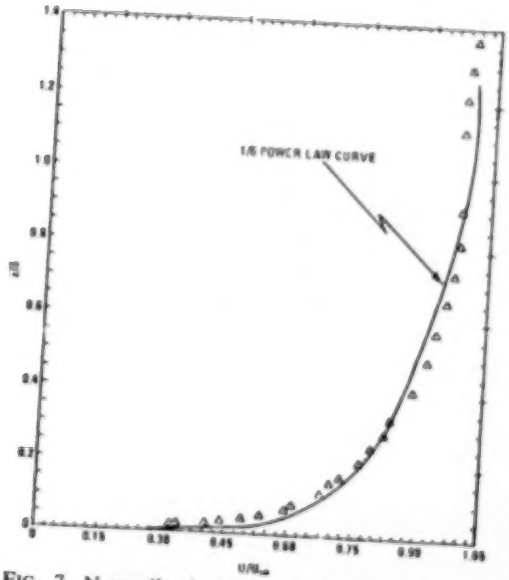

FIG. 7. Normalized mean velocity profile: x_m = 11.5 m.

Flow visualization

Flow visualization was used to evaluate the qualitative features of the dispersion and to determine sampling positions for the concentration measurements. Plume trajectories were examined for all three stack heights. A general "feel" for the flow characteristics was acquired during this phase of the study, but no definitive results were determined. Slight changes in lighting, film exposure, and smoke density can make the same situation appear quite different. Hence, concentration measurements of a tracer released from the source were relied upon for the quantitative evaluation and comparison of dispersion.

Dispersive characteristics of the boundary layer

Dispersion in the simulated suburban boundary layer was examined by measuring downwind concentrations of ethylene released from an isolated stack. Vertical and lateral concentration profiles were acquired at downstream distances of 0.25, 0.5, 0.86, 1.77 and 5.0 m, corresponding to full-scale distances of 75, 150, 250, 530 and 1500 m, respectively.

Sets of concentration profiles are plotted for each of the three stack heights. The figures are plotted as normalized concentration CU_∞/Q vs a length, where C is the concentration in parts ethylene per part air (by volume), U_∞ is the freestream velocity (6 m/s), and Q is the emission rate (m^3/s). The length is plotted in full-scale units and refers to the height or lateral distance depending on

the type of profile, vertical or lateral, respectively. The stack was located at the tunnel centerline ($y = 0$) and all vertical concentration profiles were taken at this location. Lateral profiles were taken at the height of the maximum concentration as determined from the vertical profiles.

Lateral and vertical concentration profiles for a ground-level source are plotted in Figs. 8(a) and (b), respectively, for the five downwind distances. Best-fit Gaussian curves were successfully drawn through the data points. There is little resolution in the data taken at small values of CU_*/Q using this type of plot.

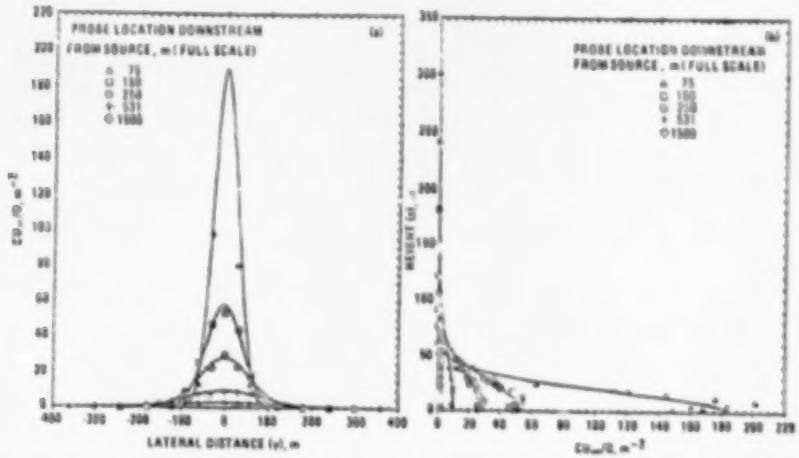

Fig. 8. Concentration profiles for a ground-level point source: (a) lateral and (b) vertical (linear plot).

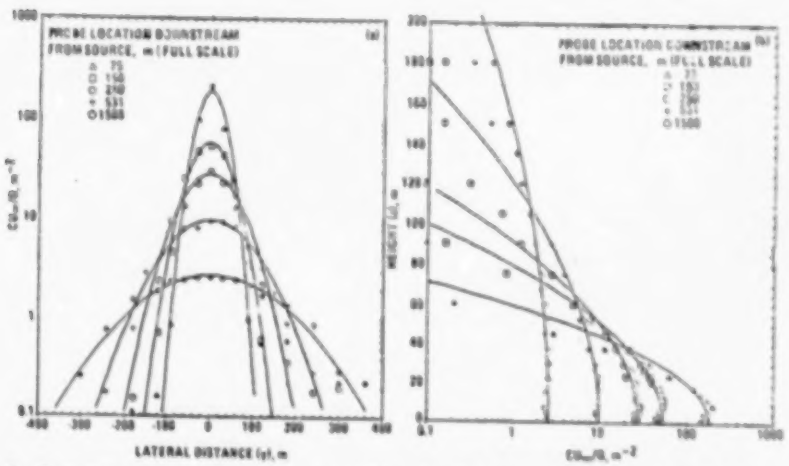

FIG. 9. Concentration profiles for a ground-level point source: (a) lateral and (b) vertical (semi-log plot).

Figures 9(a) and (b) show the same data plotted on semi-log scales; this type of plot enhances the representation of the smaller values of CU_w/Q and gives a better perspective to the Gaussian nature of the data, especially at larger downwind distances. All subsequent data are plotted using the semi-log presentation. Figures 10 and 11 show concentration profiles for point sources with release heights of 50 and 100 m, respectively. The lateral profiles are very closely Gaussian in all cases, but the vertical profiles are typically flatter than Gaussian, i.e. they decrease more slowly in the tails than do Gaussian curves of the same standard deviation.

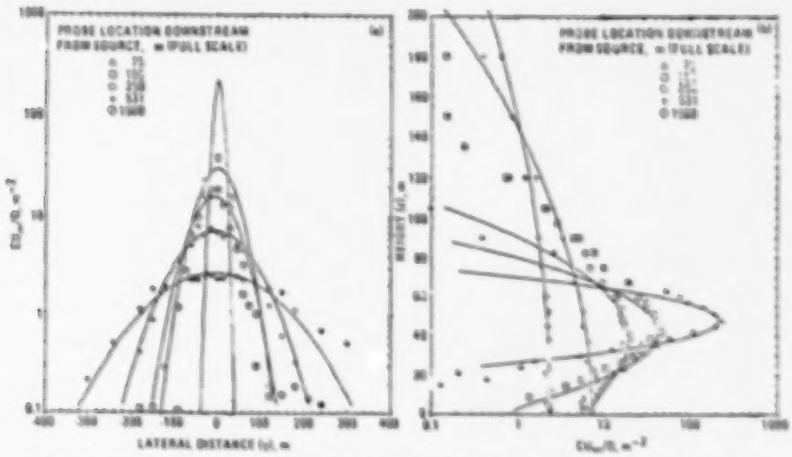

Fig. 10. Concentration profiles for a 50-m release: (a) lateral and (b) vertical.

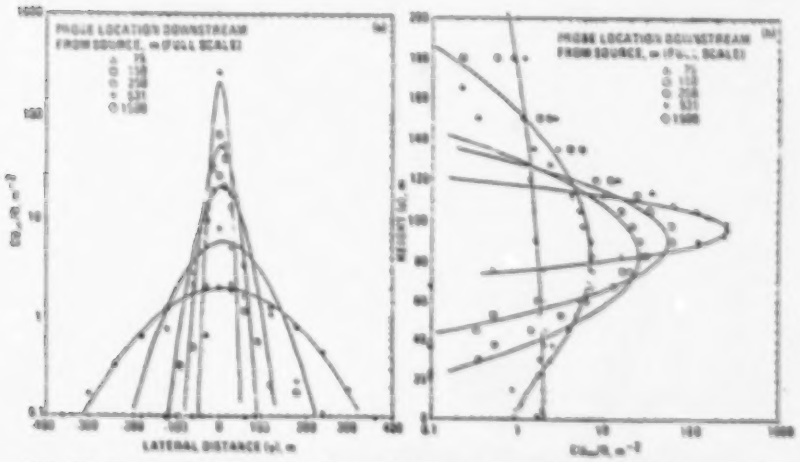

Fig. 11. Concentration profiles for a 100-m release: (a) lateral and (b) vertical.

Lateral and vertical standard deviations (σ_y and σ_z, respectively) were calculated for each profile. For the lateral profiles, the normal method of calculating the standard deviation was employed. For the vertical profiles, a computer program calculated the standard deviations of "best-fit" Gaussian curves assuming perfect reflection from the ground.

Mass-continuity checks were made on the data to insure that the amount of hydrocarbon being measured corresponded to the emission rate. A computer program was used to perform the integration $\int\int CU \, dy \, dz$, where C is the concentration and U is the velocity from a power-law fit to the velocity profile at the same downstream location. The resultant value of $\int\int CU \, dy \, dz$ was then divided by the emission rate Q. For the ideal case, this value would equal unity. Table 2 presents the continuity checks associated with each set of profiles for the isolated stack. The data agree satisfactorily.

Comparisons of plume spreading rates are important to assess the relative accuracy with which the laboratory data can be applied to full-scale situations. Figure 12 compares lateral and vertical plume standard deviations obtained for the ground-level source with those of Pasquill–Gifford (Tu70). Near the source, the data indicate high instability; they

Table 2. Continuity checks on effluent releases from the stack model

DISTANCE FROM SOURCE (m)	∫∫CU dy dz/Q		
	Ground-Level Source	50 m Source	100 m Source
0.25	1.31	1.02	0.85
0.50	1.22	0.90	0.86
0.86	1.11	0.78	0.82
1.77	1.20	0.83	0.88

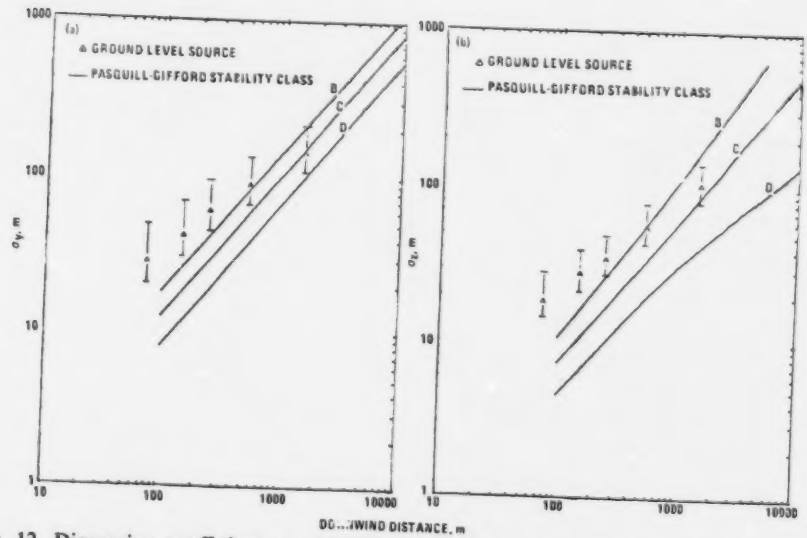

Fig. 12. Dispersion coefficients as compared with those of Pasquill–Gifford: (a) lateral and (b) vertical.

tend toward more stable values farther downstream. These results agree with other wind-tunnel data for similar comparisons (Ro78, Cou79). The discrepancy between the present data and the Pasquill–Gifford standard deviations is believed to be caused by the difference in roughness lengths. The present study represents flow over relatively rough terrain ($z_0 = 1.0$ m), whereas the Pasquill–Gifford curves were derived for terrain of considerably smaller roughness length ($z_0 = 10$ cm). To compensate for this difference, both sets of data were normalized by the roughness length z_o. Figure 13 shows the improved agreement obtained by this normalization.

Elevated-source data are compared with curves derived from the Julich experiments (Vo77). A comparison of the data for the 50 m source is presented in Fig. 14. The results compare remarkably well for neutral stability. These data correspond to the same roughness length as well as source height. Figure 15 is a plot of similar data sets for the 100 m source height. Again, the comparison is quite good for neutral stability.

The data acquired in the St. Louis experiment (Mc69) were also compared with those of the present study. This allowed a comparison with dispersion coefficients obtained in an urban area. Figure 16 exhibits a very close relationship between the two sets of data. The ground-level source data are very well correlated with the St. Louis D-stability class for both lateral and vertical plume spread. Both are low-level releases over terrain of roughness length approx. 1.0 m.

CONCLUSIONS

An atmospheric flow over a suburban environment was simulated. A model roughness length of 3.1 mm was obtained in the wind tunnel, which corresponds to a prototype roughness length of approx. 1.0 m for a 1:300 scale suburban area. Vertical profiles of velocity and turbulence intensity were representative of those found in atmospheric flows over suburban areas. A boundary layer with the above specifications may be used for a variety of transport and diffusion studies over short to moderate downwind distances.

A comparison of dispersion parameters

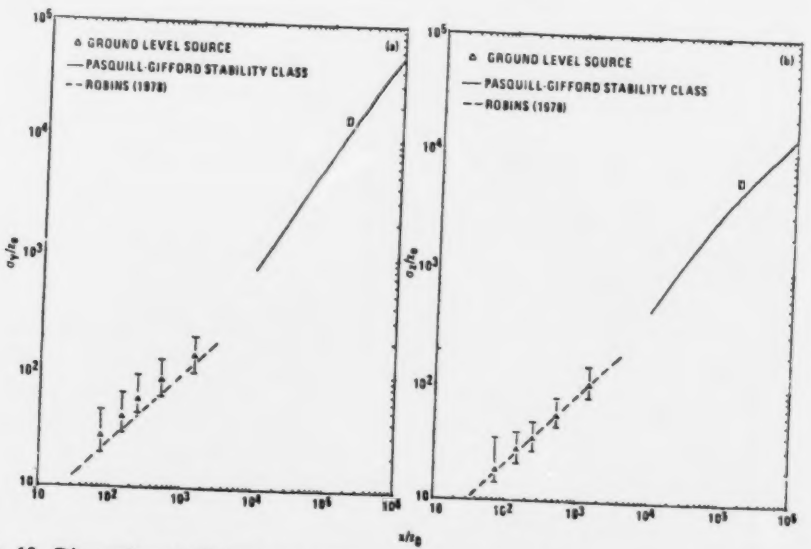

FIG. 13. Dispersion coefficients as compared with those of Pasquill–Gifford D-stability class, normalized by roughness length: (a) lateral and (b) vertical.

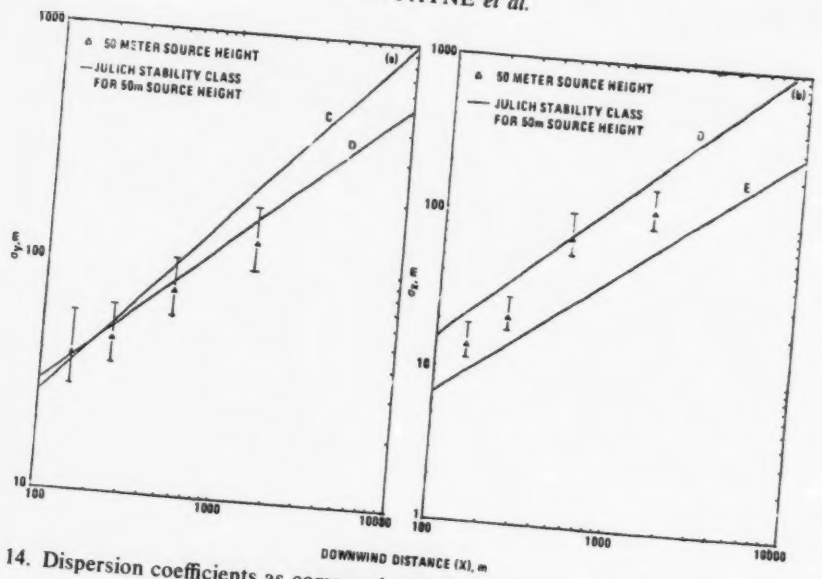

FIG. 14. Dispersion coefficients as compared with those from the Julich study for a 50-m source height: (a) lateral and (b) vertical.

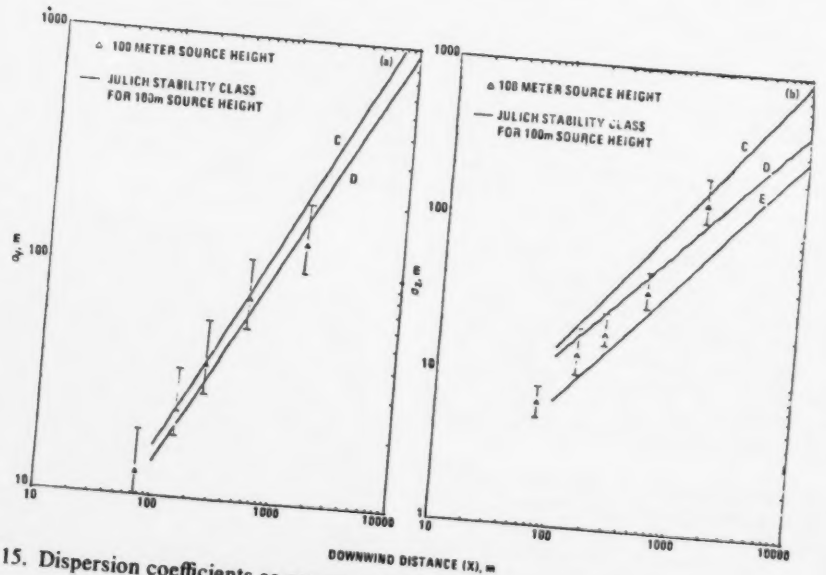

Fig. 15. Dispersion coefficients as compared with those from the Julich study for a 100-m source height: (a) lateral and (b) vertical.

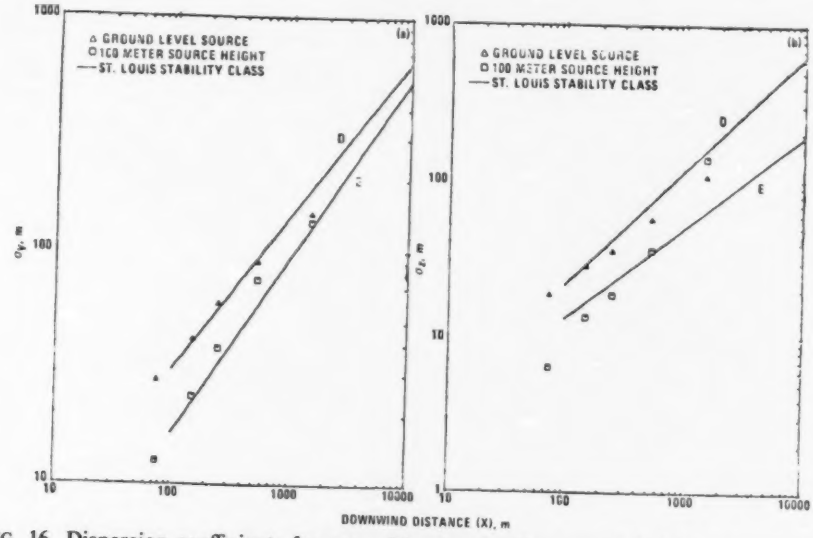

FIG. 16. Dispersion coefficients for ground-level and 100-m source heights as compared with those from the St. Louis study: (a) lateral and (b) vertical.

measured in the wind tunnel with the standard Pasquill–Gifford curves was poor; this may be expected because the Pasquill–Gifford curves were derived for surfaces with roughness length of approx. 10 cm. When data from the present study and that of Pasquill–Gifford were normalized by roughness length, the agreement was good. Dispersion parameters measured in the present study also compared well with the respective parameters measured in suburban-area field studies. Data from full-scale measurements in the Julich and St. Louis experiments tended to confirm that scale modeling of a suburban atmospheric boundary layer with properly scaled diffusion parameters had been achieved. It can be concluded that diffusion in the suburban neutral atmosphere was reasonably well-simulated in the wind tunnel.

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REFERENCES

Br75 Bruun H. H., 1975, "On the Temperature Dependence of Constant Temperature Hot-Wires Probes with Small Wire Aspect Ratio", *J. Phys. E: Rev. Sci. Insts.* **8**, 942–951.

Ca75 Castro I. P., Jackson N. A. and Robins A. G., 1975, "The Structure and Development of a 2 m Deep Simulated Suburban Boundary Layer". R/M/N800, Marchwood Engineering Laboratory, Southampton, England.

Ca80 Castro I. P. and Snyder W. H., 1980, "Three Naturally Grown and Simulated Boundary Layers", Fluid Modeling Facility Internal Report, U.S. Environmental Protection Agency, Research Triangle Park, NC. 200p.

Co69 Counihan J., 1969, "An Improved Method

of Simulating an Atmospheric Boundary Layer in a Wind Tunnel", *Atmos. Envir.* **3**, 197–214.

Co75 Counihan J., 1975, "Adiabatic Atmospheric Boundary Layers: A Review and Analysis of Data from the Period 1880–1972", *Atmos. Envir.* **9**, 871–905.

Cou79 Courtney, L., 1979, A Wind Tunnel Study of Flow and Diffusion over a Two-Dimensional Low Hill. M.S. Thesis, N.C. State University, Raleigh, NC.

Ka77 Kaufman J. W., 1977, Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 1977 Revision. NASA Technical Memorandum 78118, National Aeronautics and Space Administration.

Li76 Liu H. T. and Lin J. T., 1976, "Plume Dispersion in Stably Stratified Flows over Complex Terrain; Phase 2". EPA-600/4-76-022. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Mc69 McElroy J. L., 1969, "A Comparative Study of Urban and Rural Dispersion", *J. Appl. Meteorol.* **8**, 19–31.

Ro78 Robins A. G., 1978, "Plume Dispersion from Ground-Level Sources in Simulated Atmospheric Boundary Layers", *Atmos. Envir.* **12**, 1033–1044.

Sn72 Snyder W. H., 1972, "Similarity Criteria for the Application of Fluid Models to the Study of Air Pollution Meteorology", *Bound.-Layer Meteorol.* **3**, 113–134.

Sn76 Snyder W. H. and Lawson R. E., Jr., 1976, "Determination of a Necessary Height for a Stack Close to a Building—A Wind Tunnel Study", *Atmos. Envir.* **10**, 683–691.

Sn79 Snyder W. H., 1979, The EPA Meteorological Wind Tunnel: Its Design, Construction and Operating Characteristics. EPA-600/4-79-051. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Sn81 Snyder W. H., 1981, Guideline for Fluid Modeling of Atmospheric Diffusion. EPA-600/8-81-009. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Tu70 Turner D. B., 1970, Workbook of Atmospheric Dispersion Estimates. Office of Air Programs, Pub. No. AP-26. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Vo77 Vogt K. J., 1977, "Empirical Investigations of the Diffusion of Waste Air Plumes in the Atmosphere", *Nuc. Tech.* **34**, 43–57.

Wi78 Wilson D. J. and Netterville D. D. J., 1978, "Interaction of a Roof-Level Plume with a Downwind Building", *Atmos. Envir.* **12**, 1051–1059.